Shrimp Culture and the Environment

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Abstract

This paper reviews the interactions between shrimp culture and the natural environment. It considers and gives details of the effects of shrimp culture on the environment and the effects of environmental change on shrimp culture. Examples are given where the environmental impacts on and of shrimp culture have caused serious economic losses to shrimp farmers. The paper concludes that economic sustainability is and will continue to be closely related to how the shrimp farming industry deals with environmental problems. Strategies are considered for improved environmental management of shrimp aquaculture, and priorities are highlighted for future research on the relations between shrimp culture and the environment.

Introduction

Shrimp culture has been one of the major growth areas in worldwide aquaculture over the past decade, with 80% of production coming from the eastern hemisphere, mainly Asia. However, aquaculture production of shrimps in 1993 was only 609,000 tons, 16% less than in 1992 (Anonymous 1993). The reasons for the decline include a major collapse in China (from 140,000 tons in 1992 to 50,000 tons in 1993), a decrease in Indonesian production from 130,000 to 80,000 tons, and a further slight decline in Taiwan from 30,000 to 25,000 tons.

The development of shrimp farming industries in many countries has been accompanied by sporadic growth, local collapses of the industry, and sometimes abandonment of shrimp ponds. Such problems, widely attributed to disease outbreaks linked to environmental deterioration, have raised major questions about the sustainability of shrimp farming. Thus, although shrimp aquaculture has contributed to rural employment and economic development in the Asia-Pacific, concerns have grown over the sustainability of the industry.

There have been several reviews on the relations between shrimp culture and the environment (e.g., Macintosh and Phillips 1992, Primavera 1993). The present paper provides an overview of shrimp culture and the environment based on the literature, a major recent assessment of environmental problems in Asian aquaculture (FAO-NACA 1994), and more detailed studies carried out recently in Thailand (Office of Environmental Policy and Planning 1994, Marsden 1994).

Shrimp culture, like other aquaculture and agriculture enterprises, requires natural resources. Such enterprises may bring large profits, but if badly planned and managed, may cause irreversible environmental damage, lost opportunities, and rehabilitation costs that can easily lead to net economic loss (Odum and Arding 1991). The principal natural resources required for shrimp culture are land, water, and biological resources, including seed and feed. The available resources and the manner in which they are used determine in large part the economic success and sustainability of shrimp farming. The major issues related to these resources are discussed below.

Land Requirements

Shrimps are cultured almost entirely in land-based ponds. The area of land required depends on the culture system, although farmer decisions are modified by the availability and price of land. Traditional extensive culture systems occupy large land areas, with ponds often 2-20 hectares, sometimes even 200 hectares. Semi-intensive and intensive culture systems tend to be in smaller ponds, although the total farm area can be large.

The price of coastal land depends on the availability and competition with other coastal 'users' and also affects which areas are used. Land price also stimulates investor decisions to enter shrimp culture, and plays a role in intensification. Limited coastal land and higher land prices such as in Taiwan (Liao 1990, 1992) stimulates development of more intensive shrimp culture systems to get greater economic returns per unit area. In countries such as Indonesia and Vietnam, with cheaper and more abundant coastal land, semi-intensive and extensive systems predominate. The cost of coastal land forces shrimp farm investors to maximize profits per unit area, usually leading to more environmental problems. Shrimp farming itself can also have a dramatic effect on the price of coastal land. In the Upper Gulf of Thailand, land prices increased from US$2,500 per hectare in 1985 to $25,000 per hectare in 1989 (Macintosh and Phillips 1992).

The type of land used for shrimp farming affects the success of shrimp farming itself and the kinds of environmental impacts and conflicts with other coastal resource users. Shrimp farms have been constructed on a variety of coastal lands, including salt pans, agricultural lands, abandoned and marginal lands, and wetlands, including ecologically important mangroves and marshes. The traditional preference for low-lying coastal wetlands has changed to an industry preference for supra-tidal land where ponds are cheaper to construct and drain and the soils are normally better.

Land use for shrimp culture varies considerably and it is not possible to generalize. For example, in Thailand, land use for shrimp culture varies from province to province. Earlier studies in the Upper Gulf of Thailand showed that only 21% of new shrimp ponds were converted from mangroves (Csavas 1990). A recent study in the south of Thailand showed that only 14% of shrimp farms were in mangrove areas and 49% were converted from rice fields (Table 1).

Table 1. Land use prior to construction of intensive shrimp ponds in the southern provinces of Thailand (S Piamsomboon, personal communication).

Land use	% of farms
Rice fields	49.0
Orchards	27.5
Extensive shrimp ponds	3.9
Mangrove forests	13.7
'Unproductive' or 'unclassified' land	5.9

Productive agricultural lands have been converted into shrimp ponds in several countries (Mahmood 1987), although in many instances the use of marginal or unproductive land for shrimp culture makes more economic sense. Conversion of land to shrimp farming has been reported to lead to adverse ecological impacts or conflicts with other users (e.g., Primavera 1992). Conflicts arise when impacts spread beyond the confines of the shrimp farm, such as in the Philippines, where use of freshwater from underground aquifers has resulted in subsidence of coastal land (Primavera 1989). Subsidence around the Pingtung coastal area in Taiwan in 1970-83 was 0.3-2 meters, mainly due to groundwater extraction for shrimp and eel ponds (Chiang and Lee 1986). Not surprisingly, this led to very significant conflicts between shrimp and fish farmers and other coastal inhabitants.

Salination of soils as a result of shrimp farming further devaluates already marginal agricultural land. A remote sensing study in two provinces in southern Thailand showed that 3,344 hectares of shrimp ponds had led to salination of 1,168 hectares of agricultural land, mostly rice fields (Office of Environmental Policy and Planning 1994).

The short-term profits possible with shrimp farming result in very rapid changes in land use and new entrants create pressure to construct ponds on lands only marginally suitable for shrimp farming. In some places, the existing infrastructures (particularly water supply systems such as canals) are inadequate to support the quickly developing industry. In the Upper Gulf of Thailand during the 1980s, many intensive shrimp ponds were built on old extensive shrimp farms or salt pans. Although this was probably a good use of available resources, these old pond sites rarely had the water supply to cope with the higher water demand of more intensive culture. The effect of this can be seen in Samut Songkhram, Samut Prakan, and Samut Sakhon where the shrimp industry has declined since 1989 due to overproduction, water pollution, and the inadequate water supply from the *klongs* or canals (Macintosh and Phillips 1992).

Mangroves and Shrimp Culture

Mangrove forests occur throughout the tropics and in some subtropical areas on sheltered shores with soft intertidal sediments (Macintosh 1982). The impact of shrimp culture on mangroves has received considerable attention, both in the scientific and popular press (Primavera 1991). Although it is true that expansion of shrimp culture has led to destruction of mangroves, shrimp culture is just one of many coastal activities leading to the loss of the region's mangroves

(FAO-NACA 1994) and yet is often unfairly blamed. Csavas (1990, personal communication) has also pointed out that much recent semi-intensive and intensive shrimp culture has occurred in non-mangrove areas, or in mangrove areas earlier cleared for extensive shrimp or fish culture, or other purposes. In China (the major shrimp producer in 1991), shrimp ponds are mostly in non-mangrove areas.

In Malaysia, shrimp farms have encroached onto mangrove reserves (Chua et al. 1989b). In Indonesia, most of the estimated 200,000 hectares of shrimp ponds have been converted from former mangrove forests. The total pond area is just 5% of the massive Indonesian mangrove resource of 4,251,011 hectares, but construction of ponds for shrimp and milkfish culture has contributed to very significant local denudation in Java, Sulawesi and Sumatra (FAO-NACA 1994). In the Philippines, a combination of shrimp and milkfish culture is responsible for reducing the mangrove area from 448,000 hectares in 1968 to 110,000 hectares in 1988, with 60% of this decrease thought to be due to conversion to milkfish ponds (Primavera 1991, 1993). The Philippine Fisheries Code promulgated in 1975 slowed down the conversion but shrimp culture during the 1980s removed an additional 30,000 hectares for new ponds.

In Thailand, 38.3% of mangrove areas lost between 1979 and 1986 were used for aquaculture; this means 38,000 hectares or 13% of the 287,300 hectares of mangrove resource in 1979 (Arbhabhirama et al. 1988). However, it is important to avoid generalizations. Shrimp ponds in some parts of the country have certainly encroached on mangrove areas, but other major shrimp farms are in areas with limited mangroves, such as Songhkla in the south (Table 1). In the Mekong Delta in Vietnam, clearance of mangroves for timber and shrimp farming has been serious, estimated at 60,000 hectares between 1985 and 1988 and still continuing, adding to the catastrophic losses of mangrove forests during the Vietnam War (Mekong Secretariat 1992).

The loss of mangrove areas can adversely affect the ecology, economics, and societal life in coastal localities, as described by several authors (e.g., Macintosh 1982, Snedaker and Getter 1985, Bailey 1988, Primavera 1991). Some of the problems that emerge where there is large-scale conversion of mangroves to shrimp ponds can be seen in the Mekong Delta of Vietnam (Table 2, Hong 1993). Loss of mangroves has serious implications for the sustainability of various coastal activities. The productivity of some coastal fisheries appears to be positively correlated to the abundance of mangrove forests adjacent to the fishing grounds (Turner 1977, Martosubroto and Naamin 1977, Kapetsky 1987). In Chantaburi, Thailand, fishermen reported declines in catches due to restricted access to previously accessible mangrove areas (Sirisup 1988).

In Bangladesh, expansion of shrimp farming into mangrove areas has reduced fish catches and the socio-economic condition of traditional coastal fishermen (Asian Institute of Technology, unpublished data). The loss of life and structural damage caused by the 1991 cyclone in southeastern Bangladesh may have been made worse by the earlier loss of mangroves, and coastal shrimp ponds themselves suffered severe damage (Anonymous 1991). The economic impacts of mangrove destruction ultimately can be very significant and may far outweigh the short-term benefits from conversion to shrimp ponds.

There is a growing realization that mangroves themselves can contribute to the sustainability of aquaculture. Certainly, pond construction should not proceed indiscriminately in mangrove areas (Csavas 1988). The traditional extensive culture method uses up large areas of mangrove, but has very low productivity in return. For this reason, extensive culture systems are difficult to justify, neither ecologically or economically, as a way for long-term sustainable use of coastal resources. Turner (1977) has shown that one hectare of mangroves can yield 767 kg of wild fish and crustaceans, more than the yields in extensive systems (usually considerably less than 500 kg/ha-yr).

Table 2. Adverse effects on the environment of the loss of mangrove forests in the Mekong Delta of Vietnam. Modified from Hong (1993).

Adverse effects
Increased vulnerability to storm damage and coastal erosion in Tien Giang, Ben Tre, Cuu Long, and Minh Hai provinces
Salt intrusion damaged 2,000 hectares of rice fields at Gan Gio district, Ho Chi Minh City in 1991
Decline in abundance of shrimp postlarvae and in the yields of extensive shrimp ponds from 297 kg/ha in 1986 to 153 kg/ha in 1988
Decline in the mangrove-dependent mudcrab population and reduced export earnings
Acidification of pond water and soil through formation of acid sulfate soils

Of additional concern is that the shrimp ponds on mangrove land often support profitable shrimp culture for only short periods. Mangrove areas are often not the places to build sustainable aquaculture farms. In extensive culture systems, loss of mangrove nursery areas can affect the supply of postlarvae for the ponds, a trend that has appeared in Bangladesh and may be threatening the sustainability of traditional shrimp culture in the Mekong Delta of Vietnam (Mekong Secretariat 1992). In semi-intensive or intensive shrimp culture, acid sulfate soils common in mangrove areas may affect farm sustainability.

Mangroves protect the ponds built behind them and influence considerably the water quality in shrimp farming areas. Mangroves may remove nutrients, heavy metals, suspended solids, and toxic hydrocarbons (Landers and Knut 1991). Thus, coastal water quality may deteriorate through loss of the mangroves' filtering capacity. Conversely, mangroves can 'clean up' shrimp pond effluent. Robertson and Phillips (1994) have calculated the areas of *Rhizophora* mangrove forest required to remove nutrients from shrimp pond effluents (Table 3). These area estimates may be useful in local area planning.

Thus, there are mutually supportive functions of aquaculture and mangroves and there is now growing interest in integrating mangrove and shrimp farming in the coastal zone (de la Cruz 1995). Indeed, if the benefits of mangroves to sustainable shrimp culture are more clearly recognized, shrimp farming may provide an additional economic justification to preserve mangroves. In Indonesia, Thailand, and the Philippines, a mangrove buffer zone between the sea and the shrimp ponds has been advocated. Such zones can potentially serve the interests of both the conservationists and the shrimp farmers. Indeed, some large private farms in Thailand now retain a protective mangrove buffer (personal observations). Further research on the mutual benefits between mangroves and aquaculture would be useful in order to develop planning guidelines.

Table 3. Estimates of area of *Rhizophora* mangrove forest that would be required to remove the nitrogen and phosphorus loads produced during the operation of shrimp ponds (Robertson and Phillips 1994).

Nutrient	Ratio (area mangrove forest: area shrimp pond) Semi-intensive	Intensive
Nitrogen	2.4 : 1	7.2: 1
Phosphorus	2.8 : 1	21.7 : 1

Water Requirements

The quality and quantity of water used for shrimp culture is a critical factor affecting the sustainability of the industry. Water quality is critical in the hatchery and during the grow-out period in ponds. Most practical handbooks recommend that the water for shrimp culture should be free from agricultural, domestic and industrial pollution and be within the required salinity and temperature ranges (Apud et al. 1989). However, urbanization, industrialization and chemical use in agriculture is make it extremely difficult to find such pollution-free waters in many coastal areas. There is growing evidence that shrimp culture is severely threatened by growing water pollution in Asia (Chua et al. 1989a) as well as other parts of the world (Aiken, 1990).

The recent review by FAO-NACA (1994) has concluded that external environmental changes threaten the sustainability of shrimp culture in Asia. Unexplained shrimp mortalities in several countries — including Bangladesh, Thailand, China, Indonesia and the Philippines — have been blamed on agricultural or industrial pollution. In Taiwan, pollution of coastal waters was thought to have contributed to the collapse of the industry in 1987. In Thailand, pollution of water supplies with contaminants from industry, agriculture, and sewage is thought to have been at least partially responsible for the losses of the shrimp industry in the Upper Gulf of Thailand since 1989. Given the sensitivity of shrimps (particularly young stages) to pollutants, shrimp culture is highly risky in areas of intense agricultural, urban, and industrial development. It is often difficult to identify the cause of the water quality problems that crop up. Sadly, most studies on the water quality problems faced by shrimp farms do not assess the relative effects of external factors against those generated by the shrimp farms themselves.

Contamination of water supplies with organic material, hydrocarbons, heavy metals, and pesticides is significant in some shrimp farming areas (FAO-NACA 1994). Microbial contamination of shrimps with *Vibrio* and *Salmonella* have been reported, but it is unclear whether this is due to water pollution or poor handling and processing. The effects of coastal eutrophication and red tides on shrimp culture have been extremely serious, as in China in August

1989, when a *Gymnodinium* bloom around the Bohai Sea caused an estimated US$67 million worth of damage to *Penaeus chinensis* farms (FAO-NACA 1994).

The quantity of water required by shrimp culture has some implications for sustainability. The amount required by shrimp hatcheries is small compared to the amount required by ponds (Phillips et al. 1993). Extensive shrimp farms require less water, and total water demand normally increases with intensification as more water is required to flush away metabolites and other wastes. In intensive culture systems, demand can easily outstrip supply in areas with poor tidal flushing or limited water. The switch from extensive to intensive culture puts pressure on the often already limited water resources, and leads to greater water pollution. However, there are trends towards reduced water use in intensive shrimp ponds (Office of the Environmental Policy and Planning 1994). Table 4 shows that water exchange in intensive farms in southern Thailand averages only 14% per day, 6-7 days each month.

Table 4. Water exchange in intensive low-water use shrimp ponds in southern Thailand, from a survey of 80 such ponds in Ranot and Huasai Districts. From Office of Environmental Policy and Planning (1994).

Month of culture	Water exchange	
	Days/month	Amount/day (%)
1	12.3	4.2
2	5.8	15.3
3	4.3	16.9
4	3.9	19.0
Average	6.6	13.8

The use of fresh water from underground aquifers for intensive shrimp farming in Taiwan, the Philippines and Thailand has resulted in saltwater intrusion and salination of freshwater aquifers (Primavera 1991, Liao 1992). Discharge or seepage of saline water from shrimp ponds has caused salination of freshwater supplies in Bangladesh (Mahmood 1987), Indonesia (Cholik and Poernomo 1987), and Thailand (PSU 1991, Office of Environmental Policy and Planning 1994). A survey in Chantaburi, Thailand showed that 16-22% of agricultural farms were affected by saline intrusion linked to shrimp pond expansion (Sirisup 1988). Salination seems to be particularly acute in areas where inland shrimp ponds receive pumped saltwater. These problems are partly due to the widely made recommendation to site shrimp ponds behind mangrove areas.

The use of fresh water to dilute salt water also gives rise to problems (Primavera 1991). However, more and more farmers (particularly in Thailand) now realize that tiger shrimp can be cultured successfully using full sea water, so there is now little need for farmers to dilute salt water. This trend has potential to reduce environmental impacts.

The economic impacts of freshwater use and salination have not been assessed, but are likely to offset some of the benefits of shrimp farm development. Freshwater supplies are limited in many coastal areas in Asia and deliberate use for, and salination by, shrimp farms can not be justified in either social or economic terms. Abstraction of fresh water from underground aquifers is now banned in Taiwan and parts of Thailand. Proper site selection and well designed drainage systems can certainly help to reduce the problems.

Seed Requirements

In some countries, the shrimp industry still relies on the wild shrimp fishery for broodstock and even postlarvae. In traditional extensive systems such as the Indian *bheries* and Indonesian *tambaks,* farmers relied on inflowing tidal water to bring postlarvae into the ponds. Farmers in the Mekong Delta also rely heavily on natural supplies of postlarvae (Mekong Secretariat 1992). Catches of wild tiger shrimp postlarvae have declined in India (Silas 1987), Bangladesh (Mahmood 1987), and Vietnam (Mekong Secretariat 1982). There may be natural fluctuations in abundance of postlarvae, but other aggravating factors include overfishing, pollution, and habitat destruction.

Deliberate stocking of either wild or hatchery-reared postlarvae has become the common practice in shrimp farms. The high demand for postlarvae, and the unpredictable natural supply, have led to the development of hatcheries to support the semi-intensive or intensive shrimp farms in many countries. Indeed, the development and dissemination of the hatchery technology for tiger shrimp was the key to the subsequent growth of shrimp culture in Asia (Liao 1990, Csavas 1990). In Vietnam, India, and Bangladesh, hatcheries are rapidly being developed to meet the needs of the expanding and intensifying grow-out ponds.

The quality and quantity of postlarvae affect the sustainability of shrimp culture. Some farmers still prefer wild postlarvae for pond stocking, and in Sulawesi, which still has large areas of *tambak,* this view is reflected by higher price. The poor quality of hatchery-reared stock in Taiwan contributed to the crash of the tiger shrimp industry there (Lin 1989, Chen 1990). Quality testing, improved hatchery technology, and greater awareness of the importance of postlarval quality are necessary to improve quality. Shrimp farmers in parts of Java are aware of the poor quality of antibiotic-treated shrimp and request antibiotic-free postlarvae from hatcheries, thus creating some market pressure for hatchery operators to avoid overuse of antibiotics (FAO-NACA 1994).

An important environmental issue is the impact on other Fisheries of the harvesting of wild shrimp postlarvae. Silas (1987) estimates that 10 kg of fish and shrimp larvae are killed during the collection of 1 kg of tiger shrimp postlarvae in the Sunderbans of West Bengal, India. BOBP (1990) reports that up to 5,000 postlarvae of other fishes and shrimps are killed for every 100 marketable postlarvae (including *Macrobrachium rosenbergii)* collected in Bangladesh. BOBP (1990) has developed alternative environment-friendly methods for seed collection combining conservation measures with methods to increase economic returns to fisher families.

Although the shrimp culture industry is moving away from reliance on wild-caught postlarvae, virtually all hatchery broodstocks in Southeast Asia come from the wild. The broodstock supply is unpredictable in some countries, although not yet regarded as a significant constraint to industry progress (Fast and Lester 1992). However, overfishing, pollution, and loss of coastal habitats will probably lead to future scarcity of broodstock. Some countries have or are considering restrictions on broodstock collection and export to protect wild shrimp populations. Loss of wild shrimp resources represents loss of broodstock and genetic material for future selective breeding programs. In Japan, stocking programs have already been implemented to ensure the future of wild shrimp Fisheries (Fast and Lester 1992). In Thailand, tiger shrimps are also stocked in coastal waters (Department of Fisheries, personal communication). The effects of such stocking programs on wild populations is uncertain.

The availability of tiger shrimp broodstock may depend on the maintenance of coastal nursery habitats. For example, the tiger shrimp stocks in central Vietnam are thought to rely on a small but possibly critical coastal or riverine mangrove habitat (A Robertson, personal communication). The loss of such habitats may have serious consequences for the sustainability of the shrimp industry. FAO-NACA (1994) has recommended action to better identify and protect coastal habitats and stocks of marine shrimps and fishes critical to the long-term survival of the aquaculture industry.

Due to the uneven supply and demand of shrimp postlarvae and broodstock, there has been a considerable movement of animals, both within and between countries (De Silva 1989). For example, the Indo-West Pacific *Penaeus monodon* has been introduced to central America (Welcomme 1988, Lightner et al. 1989) and the East Pacific *P. vannamei* and *P. stylirostris* have been brought into the Philippines (Juliano et al. 1989). Four species (*P. stylirostris, P. vannamei, P. brasiliensis* and *P. schmitti)* have been brought into Taiwan from Latin America at various times (Liao and Liu 1989). Chiba et al. (1989) reports on the introduction of *P. chinensis* from China to Japan. A native of China, Korea, and Japan, *P. japonicus* has been introduced to Singapore from Japan (Chou and Lam 1989). Transfers of shrimp postlarvae or adults within the species' native ranges are also common in Asia, for example, *P. monodon* from the Philippines and Malaysia to Taiwan (Liao and Liu 1989).

Experience with aquatic species in general indicates that a number of problems may arise following the introduction of new species and even transfer of animals within their native range. Introduced species bring in diseases and parasites, disrupt the host community through competition, predation and stunting, and cause changes in habitats, genetic diversity, and even coastal socioeconomics (Welcomme 1988). Pathogens can be highly virulent to new species (Alderman et al. 1984, Welcomme 1988). Non-native shrimps escape from shrimp culture facilities into natural waters (Anonymous 1990), and pathogens from cultured shrimps are transmitted to wild stocks (Lightner and Redman 1992, JF Turnbull, personal communication). However, there is little concrete information on the effect of introductions and transfers on cultured and wild shrimps.

Shipments of shrimps have certainly helped the spread of pathogens. The infectious hypodermal hematopoietic necrosis virus or IHHNV is suspected of having spread from its natural range on the Pacific coast of Latin America to the Middle East and Asia through shipments of infected shrimps, and monodon baculovirus (MBV) has been found in tiger shrimp stocks introduced to Hawaii, Mexico, and Tahiti from southeast Asia and Taiwan (Lightner et al. 1989).

MBV is now also found in many wild-caught tiger shrimps in Southeast Asia, showing that the virus has crept into wild populations (or may already be widespread in the wild?). It is easy to see how this has happened. For example, about 10 million tiger shrimps were washed into the sea from ponds during serious flooding in southern Thailand in 1988. The recent economically serious outbreak of 'yellowhead' disease in shrimp farms in Thailand seems to have been transmitted by wild shrimps (personal consultations). Thus, pathogen transfer to wild stocks can also have serious implications for the shrimp industry, as pathogens are impossible to eradicate in the wild and thus likely to come back to the ponds. The effect of pathogens on wild stocks is also uncertain. The recent FAO-NACA (1994) study has recommended further research on the interactions between cultured and wild stocks, including pathogen transfer, as a basis for improved understanding and regulations.

The introduction and transfer of shrimps and the spread of shrimp pathogens will likely come under close scrutiny in relation to international trade, following the Convention on Biological Diversity, which came into force on 29 Dec 1993 (Lesser 1994). There will likely also be increasing market pressure on the shrimp export industry to control disease problems. For example, the European Community is considering provisions for registration of all farms exporting aquatic products to the EC, and such registration would include the disease status. Importing countries will become increasingly conscious of the disease status of shrimp stocks from exporting countries. Such registration and other regulations (biologically justified or not!) will become increasingly common as shrimp markets become more saturated and competitive and as world trade markets change according to the General Agreement on Tariffs and Trade (Repetto 1994, Lesser 1994). Positive publicity and public awareness campaigns may be necessary to prevent unfair actions being taken against shrimp-producing countries.

Feed and Fertilizer Requirements

The quantities of fertilizers and feeds used, and their effects on sustainability and the environment vary with the intensity of culture. Extensive systems have relied on natural productivity, sometimes supplemented with small amounts of fertilizers (usually organic). Semi-intensive and intensive systems require greater inputs of fertilizers and supplemental feeds, or complete feeds. The use of formulated diets is becoming increasingly common in Southeast Asia in support of intensive farming systems. The nutrient and phosphorus budgets for semi-intensive and intensive shrimp farms are shown in Table 5. Such data demonstrate that a high proportion of the nitrogen and phosphorus added to a shrimp pond as feed is wasted. The data also suggest an economic loss through poor feed utilization and a potential for on-farm water pollution.

The use of 'trash' fish and locally formulated 'fresh' diets is still common in some countries. In China, cultured shrimps are fed live and dead marine and brackishwater mollusks, small crustaceans, and polychaetes (Liu 1990). Both the use of fresh diets and intensive feeding with formulated commercial diets affect water quality and thus the environment. For example, the use of fresh diets is thought to have contributed to the severe shrimp losses in China.

Chemotherapeutants

There has been considerable discussion about the effects on the environment of chemotherapeutants used in shrimp ponds to disinfect, prevent or treat diseases, to condition soil and water, to kill pests, and as feed additives. Antibiotics and several others of these compounds are potential threats to human health and the environment, as well as to shrimp health and product quality. For example, drugs like furazolidone and common chemicals like malachite green are

Table 5. Nutrient budgets for 10-hectare shrimp ponds in terms of the amounts of nitrogen and phosphorus in the feed input, shrimp output, and waste loads (wastes expressed in two quantities). Modified from Gavine and Phillips (1994).

Culture System	Nitrogen				Phosphorus			
	Feed (t/yr)	Shrimp (t/yr)	Waste (t/yr)	Waste (kg/t shrimp harvested)	Feed (t/yr)	Shrimp (t/yr)	Waste (t/yr)	Waste (kg/t shrimp harvested)
Semi-intensive ponds Potential harvest 3 t/ha-crop, 9 t/ha-yr; FCR 1.4	2.98	2.66	0.29	9.7	0.45	0.18	0.27	9.0
Intensive ponds Potential harvest 9 t/ha-crop, 27 t/ha-yr; FCR 2.0	38.3	23.99	14.34	53.1	5.83	1.59	4.24	15.7

Feed conversion ratio FCR = kg dry feed/kg wet shrimp.

potential carcinogens or allergens (Schnick 1991). The chemicals used in intensive shrimp farms in southern Thailand are shown in Table 6. Although of concern, these chemicals from shrimp culture are likely to have a smaller environmental impact than the agricultural chemicals used in most countries in the region (FAO-NACA 1994). Nevertheless, the risks exist and the problems certainly require better understanding.

Table 6. Chemicals used by 80 shrimp farmers in Songkhla and Nakhon Sri Thammarat in southern Thailand. Chemicals used by <5% of the farmers are not listed. From FAO-NACA (1994).

Chemicals	% Farmers	Reason for use
Lime	24.5	pH control in pond preparation
Dolomite	6.4	Pond preparation
Zeolite	26.1	Water quality control
Teaseed cake	31.8	Predator control
Benzalkonium chloride	9.6	Water disinfectant
Oxytetracycline	17.3	Control of bacterial diseases
Other chemicals	6.7	Control of diseases

Specific examples illustrate the environmental dangers of widespread use of antibiotics in aquaculture. Studies on salmon farms have shown that antibiotic residues can be extremely persistent in marine sediments and lead to the development of antibiotic resistance among bacteria (Aoki 1992). Use of oxytetracycline in Taiwan, Thailand and the Philippines has resulted in resistant strains of *Vibrio,* such that treatment of *Vibrio* infections is now extremely difficult (Nash 1990). Similar increased resistance to chloramphenicol has emerged through misuse of antibiotics in shrimp hatcheries in the Philippines (Baticados and Paclibare 1992). Overexposure of postlarvae to antibiotics in Taiwanese hatcheries has been a major factor in the poor survival of tiger shrimps in grow-out ponds (Chen 1990).

Thus, misuse of antibiotics is a direct threat to shrimp fanning because of the emergence of antibiotic-resistant pathogens. The spread of resistant strains of bacteria in Southeast Asia has probably been made easier by the frequent intermixing of effluent and influent water in congested culture areas. Moreover, there is concern that transfer of such resistance to human pathogens could have serious repercussions on human health (Brown 1989). Chloramphenicol, a widely used antibiotic in shrimp hatcheries, is of particular concern because of its importance in the control of human *Salmonella typhae* infections (typhoid fever).

Antibiotics and some other chemicals leave residues in shrimp flesh, which may lead to rejection of products in export markets. Residues of oxytetracycline were detected in cultured shrimps from Thailand and some other countries, and shipments were rejected in Japan (Anonymous 1991). In Thailand, fairly successful efforts have been made to control the problems with antibiotics through guidelines and a monitoring program for drug residues (Kungsuwan 1992).

Wastes and Effluents from Shrimp Ponds

As shrimp farming becomes more intensive, the water quality problems created by farm effluents increase. Although minor local pollution has resulted from the discharge of hatchery wastewater, most environmental concerns relate to the discharge of effluents from grow-out ponds. To address the effects of shrimp pond effluents on the sustainability of shrimp farming, it is important to understand the nature and quantity of the waste materials and effluents from shrimp farms.

Extensive shrimp culture systems are characterized by low stocking densities, little or no fertilization or supplemental feeding, and low water exchange rates limited to spring tide periods. In consequence, extensive farms do not generate significant amounts of wastes and indeed may be net removers of nutrients and organic matter (Macintosh 1982). The fact that extensive ponds in Indonesia and the Philippines have been used for shrimp and fish culture for centuries testifies to their potential sustainability. The main effluent problem in extensive ponds may be the very acidic (pH 2.7-3.9) discharges from new ponds built on acid sulfate soils (Cholik and Poernomo 1987, Phillips et al. 1993).

Semi-intensive shrimp farms receive more fertilizers and supplemental feeds, and intensive farms rely on complete feeds. As a consequence, more nutrients, more organic matter, and more of other wastes affect the water quality more severely (Table 5). Supplemental and complete feeds are the most important inputs that contribute to the wastes from intensive culture systems, although fertilizers, antibiotics, and other drugs and chemicals add to the load. The wastes from shrimp ponds consist of: (a) solid matter, a mixture of uneaten food, feces, phytoplankton, and colonising bacteria, and (b) dissolved matter such as ammonia, urea, carbon dioxide, and phosphorus (Macintosh and Phillips 1992). The wastes include amino acids, proteins, fats, carbohydrates, fiber, minerals, and bacteria (Boyd 1989).

Feed quality is an important factor affecting waste output in aquaculture. Loadings of nutrients and organic matter are higher from fish fed 'trash' fish and fresh diets than from those receiving pelleted moist or dry diets (Warrer-Hansen 1982). Wickins (1985) found that fresh diets, infrequent feeding, and high stocking densities increase nitrogen loads from shrimps in recirculating tank systems. 'Trash' fish and invertebrates, advocated as an economic feed in some countries (Liu 1990), can lead to higher waste loads, poor pond water quality, and greater pollution of the receiving waters next to the farm.

The effluents discharged from ponds reflect the internal processes in the pond. The effluent quality during normal operation will be similar to the water quality in the pond. Effectively managed ponds are well mixed with water quality characteristics within acceptable range for shrimps. Table 7 shows the characteristics of inflow water, normal effluent, and effluents during harvest in nine intensive shrimp ponds in Thailand (Satapornvanit 1993). Water quality deteriorates during the grow-out cycle due to increasing feed inputs and shrimp biomass; thus the effluent has higher nutrients and organic matter than the influent, particularly at harvest. Boyd (1978) and Bergheim et al. (1984) demonstrated high 'shock' loads of solids, iochemical oxygen demand, nitrogen, and phosphorus during tank cleaning, loads that are several times higher than at other times.

Table 7. Water quality of the influent and effluent water of nine shrimp ponds in Thailand. Samples were collected throughout one grow-out cycle, Jan-May 1993. Modified from Satapornvanit (1993).

Water type	Concentration (mg/1)							
	Total N	Total P	Orthophosphate	Nitrite	Nitrate	Total ammonia	NH3	Org Carbon
Influent 31.7-34.3 ppt 27.8-30.8°C pH 7.2-8.1	0.28-0.77	0.05-0.29	<0.05-0.12	0.001-0.012	0.02-0.41	<0.05-0.63	<0.001-0.009	<0.10-19.02
Effluent (normal operation) 35-37 ppt 28.8-30.2°C pH 7.4-8.3	1.46-3.11	0.25-0.70	<0.05-0.14	0.003-0.043	0.01-0.43	<0.05-1.70	<0.001-0.006	18.86-37.25
Effluent (harvest) 36-39 ppt 29-32°C pH 7.0-8.3	1.57-5.06	0.21-1.30	<0.05-0.24	0.004-0.033	0.01-0.09	0.51-1.51	0.003-0.198	17.24-39.44

The effects of waste materials can be seen within the pond. The dissolved nutrients and organic solids stimulate the rapid growth of bacteria, phytoplankton, zooplankton, as well as the benthos. Phytoplankton dynamics affects the effluent quality, with high dissolved nutrient loads after phytoplankton blooms 'crash' in intensive fish ponds (Krom and Neori 1989). These plankton blooms are a common problem in shrimp farms, particularly during sudden changes in weather.

Inspite of mechanical aerators in intensive ponds, a considerable amount of detrital material and dead plankton often accumulate on the pond bottom where water circulation is more sluggish. The magnitude of this sediment accumulation can be seen in Table 8 from the work of several investigators. This accumulation results in anoxic conditions and the release of hydrogen sulfide and methane, which are significant health risks to feeding shrimps (Boyd 1989). Harvest and cleaning of ponds can be difficult due to disturbance and release of materials previously bound to the sediment (Williamson 1989). In Thailand, draining the ponds and harvesting the shrimp at the outflow gate is thought to produce less damaging effluent than using nets, which disturb the bottom sediments. For the same reason, partial harvesting by netting (to reduce shrimp biomass) is also not favored by Thai shrimp farmers.

Table 8. Sediment accumulation in intensive shrimp ponds.

Study	Amount of pond sediment		
	Dry weight (t/ha-cycle)	Wet weight (t/ha-cycle)	Volume (m^3/ha-cycle)
Tanvilai et al. (1993)	178-744		155-559
Briggs and Funge-Smith 1994	185-199	400-432	307-330
Musig (1992; in Boyd 1992)	157-290		650-850

Table 9. Sediment management in 160 intensive shrimp farms in provinces in Thailand. Data from Office of Environmental Policy and Planning (1994) and Marsden (1994).

Method of sediment management	Practising farmers (%) Songkhla/Nakhon Sri Thammarat	Chantaburi
No removal (drying and oxidation only)	1.25	0
Bulldozer (mechanical removal)	90.0	12
High-pressure hose	2.5	88
Drying + bulldozer	6.25	0

The environmental impact of different forms of pond sediments and their management requires urgent assessment. Because of environmental concerns, some countries including Thailand have already restricted the discharge of sediments from shrimp farms (FAO-NACA 1994).

Effects of Pond Effluents on the Environment

There has been much discussion of the environmental impact of shrimp pond effluents, but surprisingly little good data on the subject. A comparison of shrimp pond effluent, domestic wastewater, and fish processing effluent (Table 10) shows that the potential to pollute is much less with the pond effluents during normal pond operations. However, effluent discharged during pond cleaning is much more polluting, albeit for a shorter period. Although shrimp farm effluent is less noxious than other coastal wastewaters, large volumes are discharged, often within small areas with limited water supplies and poor flushing. This has given rise to self-pollution in shrimp culture areas. Unfortunately, it has been all too common in Asia for investors to rush into the same area, such that one farm's effluent becomes another (or the same!) farm's intake (New 1990).

Table 10. Waste load of shrimp pond effluent and other types of wastewaters. Modified from Office of Environmental Policy and Planning (1994).

Type of wastewater	BOD(5) (mg/1)	Total N (mg/1)	Total P (mg/1)	Solids (mg/1)
Shrimp pond effluent	4.0-10.2	0.03-5.06	0.05-2.02	119-225
Untreated sewage	300	75	20	500
Primary-treated sewage	200	60	15	
Biologically treated sewage	30	40	12	15
Effluent from fish-processing plant	10,000-18,000	700-4,530	120-298	1,880-7,475

BOD(5), biochemical oxygen demand over five days.

The discharge of nutrients from shrimp ponds may contribute to eutrophication, with increased primary productivity and possible phytoplankton blooms, but there is yet no evidence that this has happened. An assessment of the contribution of shrimp pond (and other aquaculture) effluents to the overall nutrient load in coastal areas in the Upper Gulf of Thailand and the Bohai Sea in China suggests that shrimp farms can hardly be blamed for coastal eutrophication (FAO-NACA 1994). Further research is necessary to put the pollution from shrimp farms within the overall context of coastal environmental conditions.

Discharge of effluents with high biochemical oxygen demand (Table 10) reduces the dissolved oxygen in the receiving waters. Release of organic matter can also be expected to result in siltation and changes in productivity and community structure of benthic organisms. Definitive studies are lacking but there is some anecdotal evidence from Thailand, Sri Lanka, and other countries, where irrigation canals became silted with organic matter discharged from shrimp farms (Phillips et al. 1993). On the other hand, recent studies in southern Thailand have shown increased mollusk harvests close to major shrimp farming areas (Office of the Environmental Policy and Planning 1994).

Where waste production exceeds the capacity of the receiving environment to dilute or assimilate the waste materials, major water pollution results. Self-pollution of shrimp culture areas by pond effluents is becoming more frequent in Asia. The major crash of the shrimp industry in Taiwan, then in the Upper Gulf of Thailand, and the losses from shrimp diseases in the Philippines, Indonesia, and China have all been linked to waste production exceeding the assimilative capacity of the local water bodies (Lin 1989, Liao 1992, FAO-NACA 1994). Chen and Sheng (1992) report deterioration of water quality due to pond effluents in Shandong and Hebei in China. On the west coast of Sri Lanka, major shrimp mortalities are blamed on pollution of the main water supply canal (the 'Dutch Canal') by pond effluents (Jayasinghe 1994).

Experience with other intensive aquaculture systems such as cage culture of Atlantic salmon or yellowtail clearly demonstrates that self-pollution is a major contributor to disease outbreaks and fish kills (ADB-NACA 1991). Such self-pollution is likely to be most serious in enclosed coastal waters, irrigation canals, or rivers subjected to heavy farming and poor water exchange. Farms located on open coastlines have better water exchange. Research is required to define the sustainable carrying capacity of coastal areas in terms of supporting production and assimilating wastes.

Effects of Water Pollution on Shrimp Farm Profitability

There is strong circumstantial evidence that environmental deterioration has played a major role in the development of disease problems now affecting shrimp ponds in Asia. Serious production losses from disease outbreaks have been reported from several countries in the region. In Taiwan, shrimp production declined from 90,000 tons in 1987 to 20,000 tons in 1989 because of disease outbreaks. Environmental deterioration was linked to the intensification of shrimp culture and the overloading of coastal waters with pond effluents and domestic and industrial discharge (Lin 1989, Chen 1990). After a short recovery, the industry collapsed again in 1993 — again due to poor environmental conditions (Anonymous 1993).

In China, shrimp production in 1993 declined to 75% of that in 1992 due to disease outbreaks and red tides. Initial unconfirmed reports suggest economic losses of US$750 million (Anonymous 1993). In Indonesia, production in central and eastern Java has been reduced by 30% in 1993 and in Medan, Sumatra, over 80% of the ponds were abandoned in 1993 due to crop failure (Anonymous 1993).

In Thailand, shrimp production from the Upper Gulf provinces was around 41,000 tons in 1989, but severe disease problems reduced production to 18,700 tons in 1991 (FAO-NACA 1994). In Samut Songkhram, Samut Prakan, and Samut Sakhon provinces in the Upper Gulf of Thailand, large areas of shrimp farms have suffered from mass mortalities and have been abandoned. Self-pollution and poor dispersal of pond effluent led to bacterial diseases. Abandoned ponds covered at least 10,100 hectares in 1991 and brought an economic loss of US$180 million worth of shrimp exports per year. Table 11 shows higher economic losses from shrimp diseases among farmers using canal water than among those using water direct from the sea.

Table 11. Economic losses from shrimp diseases in intensive shrimp farms with different water sources, Huasai and Ranot Districts, southern Thailand (Office of Environmental Policy and Planning 1994). US$1 = Baht 25.

Disease	Losses (Baht/ha-crop) Farms with water direct from sea	Losses (Baht/ha-crop) Farms with water from canals
Yellowhead disease	395,313	717,681
One month death syndrome	128,925	119,444
Gill disease	73,863	919,531
Red body disease	34,375	145,813

The concern of shrimp farmers now is to control environmental deterioration leading to shrimp diseases, but in the future, the industry may also be affected by the market perception of shrimp farming in relation to the environment (Repetto 1994). Shrimp farmers and exporters may have to build up the image of shrimps as an environment-friendly product. Indeed, with increasing competitiveness in the international shrimp markets, commercial advantage can be gained through marketing of shrimps as a 'green' product. In any event, environmental management of shrimp culture will have to be a high priority for the industry, and government (public sector) support is crucial in ensuring sustainability.

Environmental Management of Shrimp Farms

Environmental factors are closely linked to the causes of disease and the resulting production losses, but far too little is known of the pathways and interactions involved. A greater understanding of the relations between shrimp stress, diseases, and pond production would provide the basis for improved management of ponds. Improvements in the management of the pond environment can help overcome diseases. For example, faced with a decrease in production value from US$2.36 million in 1988 to $0.52 million in 1989 in a shrimp farm in the Philippines, Mancebo (personal communication) was able to restore production through improved management — reduced stocking, improved water exchange, etc.

The environmental problems affecting shrimp culture can be tackled at two levels. At the farm level, solutions come in terms of initial farm siting, design, operation, and management. At the level of the coastal zone, shrimp culture can be integrated into the coastal zone in a way that avoids adverse effects, on it from other sectors (and itself through self-pollution), and of it on other sectors.

Numerous handbooks on shrimp culture are available (e.g., Fast and Lester 1992) but these tend to concentrate on the farm as an isolated unit, with very little (if any) consideration of the potential interactions between the shrimp farm and the external environment. This approach is certainly flawed. Guidance is lacking in environmental impact assessment for shrimp farming and projects often proceed without adequate environment and site surveys. Due consideration must be given to:

- Potential risks inherent at the site (e.g., soil and water quality)
- Potential effects on the external environment (e.g., effects of effluents)
- Potential impacts from the external environment (e.g., pollution from agricultural or industrial sources)

Each of these could be incorporated into a 'risk analysis', as advocated by Wiley (1992). As investors become more aware of the risks inherent in shrimp farms, they will place more emphasis on identifying environmental problems during farm start-up and on initiating action to control problems.

Site selection is critical. However, for small-scale farmers, many of whom have little choice in terms of 'textbook' site selection, individual actions can lead to severe environmental problems and shrimp diseases in areas with poor infrastructure. Governments can assist in supplying basic infrastructure such as water supply and drainage canals. Where even this is not possible, cooperation between farmers can be encouraged to reduce problems. For example, in Surat Thani province in Thailand, farmers cooperate by taking water into ponds and discharging effluents at the same time (conventionally, green flag for intake and red flag for discharge!). Thus they avoid directly polluting each other's water supply.

Semi-intensive shrimp culture has been advocated as a means to avoid both the unproductive use of large areas of land in extensive culture and the problems with diseases and effluents in intensive culture (Primavera 1989). Hirasawa (1988) has argued that semi-intensive shrimp culture may be an economically viable method for farmers to survive fluctuations in market price. Fast and Lester (1992) have also observed that semi-intensive culture systems have the greatest profit per unit production, and have remained profitable during times of declining shrimp prices. Semi-intensive culture produces lower effluent loads (Table 5) than intensive ponds. Indeed, where farmers use a water supply with limited water exchange and limited carrying capacity, semi-intensive farming is a more equitable use of that 'capacity' than intensive farms (Gavine and Phillips 1994). As a result, a number of countries, e.g., India, Vietnam, and Bangladesh, encourage semi-intensive shrimp culture (FAO-NACA 1994). However, experiences suggest that semi-intensive systems may still not prove sustainable if large areas of ponds are developed and the carrying capacity of the environment is exceeded. In China, much of the recent collapse was in semi-intensive shrimp culture. In practice also, it is extremely difficult (impossible) to persuade farmers to remain at semi-intensive levels when they can see the immediate profits possible with intensive culture; this is true even when farmers know that what they are doing is unsustainable (Fegan 1994).

Methods can certainly be further developed to reduce the environmental impacts of more intensive shrimp culture systems. For example, as feed is the major source of self-pollution, good-quality diets can be used and excessive reliance on 'fresh' diets avoided. Feeding rates can be matched to shrimp requirements and the food conversion ratios improved. In temperate aquaculture, there has been a trend towards the use of highly digestible, 'low-pollution' diets (NCC 1990). The development of such diets, plus effective management of the ponds, reduce the pollutant loads and have long-term benefits for the shrimp farmer and the coastal environment.

Water management is also important. There is a trend towards recycle systems or minimal water use systems in Thailand (Table 4). Minimal new water is taken in for fear of taking in shrimp pathogens. Experiments have also been successful with no water exchange during grow-out in intensive shrimp ponds. The development of low water use systems has potential to reduce effluent impacts, provided water quality within the ponds can be controlled. These low water use systems will require more management skills among the farmers. Shrimp culture systems with minimal water use and controlled environments must be further studied and developed.

Treatment of Pond Effluents

The treatment of effluents can reduce the adverse effects on the water quality in the receiving waters. Fish farmers in temperate regions have been treating farm effluents for some time. A major problem with treatment is the dilute but high-volume nature of aquaculture effluents compared with other forms of wastewater (Muir 1982). Cost-effective technology is now available in several temperate countries to reduce biochemical oxygen demand, suspended solids, nitrogen, and phosphorus in aquaculture effluents (Makinen et al. 1988, Henderson et al. 1989). No such technology yet exists for shrimp culture, but there has been considerable interest among researchers to develop suitable methods to treat shrimp pond effluents. The possibilities for treatment can be split into physical, chemical, and biological methods.

The physical methods include settlement and filtration. Various physical treatments to remove suspended solids and soluble organic carbon have been evaluated. A one-hectare settling pond is required to handle shrimp pond effluents of about 900 m3/day (Rubel and Hager 1979). Filtration is the best treatment to bring suspended solids down to less than 10 mg/1 under various conditions, but the costs are prohibitive: for a 10-hectare pond in Hawaii, with effluent treated by screening and filtration (after which the water is reused), capital cost is US$137,500/ha and annual operating cost is $75,000/ha (Rubel and Hager 1980). Such costs are likely to limit the application of this technology in most Asian situations and other cheaper options need to be explored.

Settling ponds have greater potential and are now becoming more common in Asian shrimp farms, either to treat inflowing water or the effluent. In southern Thailand, one farm-level survey found that shrimp farms with a settling pond to treat inflowing water were on average more profitable (Baht 380,956/ha-crop) than those without (Baht 185,725/ha-crop) (Office of Environmental Policy and Planning 1994). Government regulations in Thailand stipulate that farms with a pond area of over 8 hectares must have a settling pond not less than 10% of the farm area. These ponds have been successful in improving the water quality of pond effluents (Gavine and Phillips 1994).

Even so, there are some problems in applying settling pond technology. First is the cost, as settling ponds take land out of productive (grow-out) use. Second are the difficulties in digging ponds on small-scale farms. Third is that shrimp pond effluent, unlike that from intensive salmon culture, contains large amounts of phytoplankton. Settling ponds, advocated for removing solid wastes, are unlikely to be completely effective in treating the effluent released during normal operation because phytoplankton is buoyant and will not easily settle. However, settling ponds can be very effective in 'capturing' solid wastes during pond harvesting and cleaning.

The effluent during normal shrimp farm operation is rich in nutrients and phytoplankton and is potentially suitable for culturing fishes, mollusks, and seaweeds. Thus, 'biological' treatment may be used. There have been experiments to treat the wastewater produced by shrimp ponds during normal operations, using oysters *Crassostrea virginica* in Hawaii (Wang 1990) and the green mussel *Perna viridis* in Thailand (NICA 1992, Lin et al. 1993). It has been found that 1 kg of oysters can remove 12-15 grams of solid matter in the presence of suspended solids of 50-110 mg/l, but oyster treatment was not enough for the effluent to meet discharge criteria (S Zhang and JK Wang, personal communication). Experiments in Thailand show that green mussels can reduce biochemical oxygen demand, organic solids, and phytoplankton (NICA 1992). However, mussels are sensitive to salinity changes, which can cause mortality or reduce filtration rates. Mussels also produce feces and pseudofeces that contribute to sedimentation.

The seaweed *Gracilaria* is an attractive species to grow in polyculture with mussels in a biological treatment system because it can remove dissolved nitrogen and phosphorus, which are not absorbed by mollusks. *Gracilaria* culture has been carried out in shrimp pond effluents (Chandrkrachang et al. 1991), but the system has yet to be taken up on a wide commercial scale. Some species or strains of *Gracilaria* are sensitive to salinity fluctuations, light limitation in turbid waters, and smothering by solid matter and microbial growth. One advantage of *Gracilaria* is that it can be processed for agar as an additional source of income.

One alternative biological method is to use mangroves to treat shrimp pond effluent, either by retention of a mangrove buffer zone close to the shrimp ponds, or by replanting mangroves for the deliberate purpose of water treatment (Robertson and Phillips 1994, Table 3). Mangroves have been used successfully as a tertiary treatment for sewage in the United States, but care is needed to avoid overloading with nutrients and organic matter. Thus, there is potential for combining mangroves and semi-intensive or intensive shrimp culture in what could be a sustainable and environmentally sound integration (de la Cruz 1995).

The quality of effluent during harvest and pond cleaning is so poor that biological treatment will not be sufficient. It is necessary to develop alternative practices or methods. Shrimps must be harvested at the pond outfall without disturbing the pond sediments. Ideally, harvesting is followed by minimal sediment disturbance, drying, and liming to enhance oxidation of organic matter (Boyd and Fast 1992). If sediments must be disturbed, settling ponds may be used. Such potentially very damaging effluent should not be discharged into common water bodies, but alternative uses must be found. In Thailand, there has been some interest in using pond sediment, rich in organic matter and nutrients, as an agricultural fertilizer. However, the sediment must be treated to remove salt, a process that also produces some effluent.

Integration of Shrimp Farming in Coastal Zone Management

The environmental problems of the shrimp industry are not only the problems of individual farms, but often of a large number of farms built in areas with limited carrying capacity. Models have been developed to predict the capacity of coastal areas to support salmon cage culture (Makinen 1991, Barg 1992), but it remains to be seen whether similar approaches could be used to determine the long-term sustainable level of shrimp farming. Models or suitable guidelines to determine in a broad way the capacity of coastal environments to support shrimp culture would be useful to government planners, investors, and insurers, who could then assess the risks of environmental deterioration and plan accordingly.

Fast and Lester (1992) predicted that worldwide there will be more regulations to control the adverse effects of shrimp farming on the environment. In Thailand, regulations cover the siting of shrimp farms, waste treatment, and environmental monitoring (FAO-NACA 1994). In the United States, shrimp farms are subject to very strict effluent controls, which Hopkins (1992) suggests are threatening the industry. Primavera (1992) suggests that the government must give tax incentives to farmers operating waste treatment ponds or facilities.

Clearly, more effective regulations are needed to govern shrimp farming. It is important that all regulations are based on a clear understanding of the interactions between shrimp farming and the environment, so that the regulations are not unnecessarily restrictive, unrealistic, and unworkable. It is also important that regulations on the shrimp industry are set within the framework of a wider coastal management plan. Such an integrated plan must also protect shrimp farming from other sources of harmful effluents. In reality, the development of such a sound and equitable regulatory framework for planning and management of shrimp farming is still a long way off in many countries.

Shrimp farming is just one 'user' of the coastal environment in Asian countries. Shrimp culture can be seriously affected by polluting industries, and itself may have adverse effects on other coastal inhabitants. Thus, sustainability will likely depend on more effective farm planning, site selection, and management that carefully consider the carrying capacity of the environment and the needs of the other users of coastal resources. Shrimp culture can make an important contribution to the economies of many developing countries. Experience shows that a more effective approach to environmental management is required, one that integrates shrimp culture into the coastal environment in a much more sustainable manner.

References

ADB-NACA. 1991. Fish Health Management in the Asia-Pacific. ADB Agriculture Department Report Series No. 1, 627 pp. Network of Aquaculture Centres in Asia-Pacific, Bangkok.

Aiken D. 1990. Shrimp farming in Ecuador. An aquaculture success story. World Aquacult. 21(1): 7-16.

Alderman DJ, Polglase JL, Fragling M, Hagger J. 1984. Crayfish plague in Britain. J. Fish Dis. 7: 401-405.

Anonymous. 1990. Viruses concern state shrimpers. The Evening Post (Charleston, South Carolina, USA), 3 May.
Anonymous. 1991. World Shrimp Farming 1991. Aquaculture Digest, San Diego, California, 45 pp.
Anonymous. 1993. World Shrimp Farming 1993. Aquaculture Digest, San Diego, California, 52 pp.
Aoki T. 1992. Chemotherapy and drug resistance in fish farms in Japan, pp. 519-529. In: Shariff M, Subasinghe RP, Arthur JR (eds) Diseases in Asian Aquaculture 1. Fish Health Section, Asian Fisheries Society, Manila.
Apud F, Primavera JH, Torres PL Jr. 1989. Farming of Prawns and Shrimps. Aquaculture Extension Manual 5, third edition. 66 pp. SEAFDEC Aquaculture Department, lloilo, Philippines.
Arbhabhirama A, Phantumvanit D, Elkington J, Ingkasuwan P. 1988. Thailand Natural Resources Profile. Oxford University Press, Singapore, 431 pp.
Bailey C. 1988. The social consequences of tropical shrimp mariculture development. Ocean Shore. Manage. 11: 31-44.
Barg UC. 1992. Guidelines for the Promotion of Environmental Management of Coastal Aquaculture. FAO Fisheries Technical Paper 328, 122 pp. Food and Agriculture Organization, Rome.
Baticados MCL, Paclibare JO. 1992. The use of chemotherapeutic agents in aquaculture in the Philippines, pp. 531-546. In: Shariff M, Subasinghe RP, Arthur JR (eds) Diseases in Asian Aquaculture 1. Fish Health Section, Asian Fisheries Society, Manila, Philippines.
Bergheim A, Hustveit H, Selmer-Olsen AR. 1984. Estimated pollution loadings from Norwegian fish farms II. Investigations 1980-1981. Aquaculture 36: 157-168.
BOBP. 1990. Shrimp seed collectors in Bangladesh. Small-Scale Fisherfolk Communities Working Paper 63, 37 pp. Bay of Bengal Programme for Fisheries Development, Madras, India.
Boyd CE. 1978. Effluent from catfish ponds during fish harvest. J. Environ. Qual. 7: 59-62.
Boyd CE 1989. Water quality management and aeration in shrimp farming. Fisheries and Allied Aquaculture Departmental Series No. 2, 83 pp. Auburn University, Alabama.
Boyd CE. 1992. Shrimp pond bottom soil and sediment management, pp. 166-180. In: Wyban J (ed) Proceedings of the Special Session on Shrimp Farming. World Aquaculture Society, Baton Rouge, Louisiana.
Boyd CE, Fast AW. 1992. Pond monitoring and management, pp. 497-513. In: Fast and Lester (1992) below.
Briggs MRP, Funge-Smith SJ. 1994. A nutrient budget of some intensive marine shrimp ponds in Thailand. Aquacult. Fish. Manage. (in press).
Brown J. 1989. Antibiotics: their use and abuse in aquaculture. World Aquacult. 20(2): 34-35, 38-39, 42-43.
Chandrkrachang S, Chinadit U, Chandayot P, Supasari T. 1991. Profitable spin-offs from shrimp-seaweed polyculture. Info fish International (6/91): 26-28.
Chen JX. Sheng NS. 1992. Shrimp culture industry in China, pp. 677-689. In: Fast and Lester (1992) below.
Chen SN. 1990. Collapse and Remedy for the Shrimp Culture Industry in Taiwan. Department of Zoology, National Taiwan University, Taipei.
Chiang HC, Lee JC. 1986. Study of treatment and reuse of aquacultural wastewater in Taiwan. Aquacult. Eng. 5: 301-312.
Chiba K, Taki Y, Sakai K, Oozeki Y. 1989. Present status of aquatic organisms introduced into Japan, pp. 63-70. In: De Silva (1989) below.
Cholik F, Poernomo A. 1987. Development of aquaculture in mangrove areas and its relationship to the mangrove ecosystem, pp. 93-104. In: Mepham RH (ed) Papers Contributed to the Workshop on Strategies for the Management of Fisheries and Aquaculture in Mangrove Ecosystems, Bangkok, Thailand, 23-25 June 1986. FAO Fisheries Report 370 Supplement. Food and Agriculture Organization, Rome.
Chou LM, Lam TJ. 1989. Introduction of exotic aquatic species in Singapore, pp. 91-97. In: De Silva (1989) below.
Chua TE, Paw JN, Guarin FY. 1989a. The environmental impact of aquaculture and the effects of pollution on coastal aquaculture development in Asia. Mar. Poll. Bull. 20: 335-343.

Chua TE, Paw JN, Tech E. 1989b. Coastal aquaculture development in ASEAN: the need for planning and environmental management, pp. 57-70. In: Chua TE, Pauly D (eds) Coastal Area Management in Southeast Asia : Policies, Management Strategies, and Case Studies. ICLARM Conference Proceedings 19, 254 pp. Ministry of Science, Technology and the Environment, Kuala Lampur; Johor State Economic Planning Unit, Johore Bahru, Malaysia; and International Center for Living Aquatic Resources Management, Manila.

Csavas I. 1988. Shrimp farming development in Asia, pp. 63-92. In: Shrimp '88. Infofish, Kuala Lumpur.

Csavas I. 1990. Shrimp aquaculture developments in Asia, pp. 207-222. In: New MB, de Saram H, Singh T (eds) Technical and Economic Aspects of Shrimp Farming. Infofish and the Fisheries Development Authority of Malaysia, Kuala Lumpur.

de la Cruz CR. 1995. Brackishwater integrated farming systems in Southeast Asia, pp. 23-36. In: Bagarinao TU, Flores EEC (eds) Towards Sustainable Aquaculture in Southeast Asia and Japan. SEAFDEC Aquaculture Department, Iloilo, Philippines.

De Silva SS (ed). 1989. Exotic Aquatic Organisms in Asia. Special Publication 3, 154 pp. Asian Fisheries Society, Manila.

FAO-NACA. 1994. Regional Study and Workshop on the Environmental Assessment and Management of Aquaculture Development. Food and Agriculture Organization, Rome; Network of Aquaculture Centres in Asia-Pacific, Bangkok, 465 pp.

Fast AW, Lester LJ (eds). 1992. Marine Shrimp Culture: Principles and Practices. Developments in Aquaculture and Fisheries Science, Volume 23, 862 pp. Elsevier, Amsterdam.

Fast AW, Shang YC, Rogers GL, Liao IC. 1989. Description of Taiwan intensive shrimp culture farms and simulated transfer to Hawaii. Sea Grant College Programme, University of Hawaii, Honolulu, 92 pp.

Fegan DF. 1994. Environmental assessment and management of aquaculture development: an industry perspective, pp. ITJ18-29. In: FAO-NACA (1994) above.

Gavine F, Phillips MJ. 1994. Review of Integrated Farming of Shrimp. Network of Aquaculture Centres in Asia-Pacific, Bangkok.

Henderson P, Bromage N, Watret B. 1989. How to design a settlement pond. Fish Farmer 12 (3): 41.

Hirasawa Y. 1988. Shrimp culture economics in Asia. Paper presented at the Seventh Session of the IPFC Working Party of Experts on Aquaculture, 1-6 Aug 1988, Bangkok. Indo-Pacific Fisheries Commission, Bangkok.

Hong PN. 1993. Mangroves in Vietnam. International Union for the Conservation of Nature. Regional Wetlands Office, Bangkok.

Hopkins JS. 1992. Shrimp culture in the United States, pp. 817-835. In: Fast and Lester (1992) above.

Jayasinghe JMPK. 1994. Sri Lanka Country Paper. In: FAO-NACA (1994) above.

Juliano RO, Guerrero R III, Ronquillo I. 1989. The introduction of exotic aquatic species in the Philippines, pp. 83-90. In: De Silva (1989) above.

Kapetsky JM. 1987. Conversion of mangroves for pond aquaculture: some short-term and long-term remedies, pp. 129-141. In: Mepham RH (ed) Papers Contributed to the Workshop on Strategies for the Management of Fisheries and Aquaculture in Mangrove Ecosystems, Bangkok, Thailand, 23-25 June 1986. FAO Fisheries Report 370 Supplement. Food and Agriculture Organization, Rome.

Krom MD, Neori A. 1989. A total nutrient budget for an experimental intensive fishpond with circularly moving seawater. Aquaculture 83: 345-358.

Kungsuwan A. 1992. Production and control of shrimp industry. Thai Fisheries Gazette 45: 841-849.

Landers JC, Knut BA. 1991. Use of wetlands for water quality improvement under the US EPA Region V Clean Lakes Programme. Environ. Manage. 15: 151-162.

Lesser W. 1994. Institutional Mechanisms Supporting Trade in Genetic Materials: Issues under the Biodiversity Convention and GATT/TRIPs. United Nations Environment Programme, Geneva, 72 pp.

Liao IC. 1990. The world's marine prawn culture industries: today and tomorrow, pp. 11-17. In: Hirano R, Hanyu I (eds) The Second Asian Fisheries Forum. Asian Fisheries Society, Manila.

Liao IC. 1992. Marine prawn culture industry in Taiwan, pp. 653-675. In: Fast and Lester (1992) above.

Liao IC, Liu HC. 1989. Exotic aquatic species in Taiwan, pp. 101-118. In: De Silva (1989) above.

Lightner DV, Redman RM. 1992. Penaeid virus diseases of the shrimp culture industry of the Americas, pp. 569-588. In: Fast and Lester (1992) above.

Lightner DV, Redman RM, Bell TA, Thurman RB. 1989. Geographic dispersion of the viruses IHHN, MBV and HPV as a consequence of transfers and introductions of penaeid shrimp to new regions for aquaculture purposes. J. Shellfish Res. 7: 554-555.

Lin CK. 1989. Prawn culture in Taiwan: what went wrong? World Aquacult. 20: 19-20.

Lin C, Ruamthaveesub P, Wanuchsoontorn P. 1993. Integrated culture of the green mussel (*Perna viridis)* in wastewater from an intensive shrimp pond: concept and practice. World Aquacult. 24(2): 68-73.

Liu JY. 1990. Present status and future prospects for shrimp mariculture in China, pp. 16-28. In: Main KL, Fulks W (eds) The Culture of Cold-Tolerant Shrimp: Proceedings of an Asian U.S. Workshop on Shrimp Culture. Oceanic Institute, Honolulu.

Macintosh DJ. 1982. Fisheries and aquaculture significance of mangrove swamps, with special reference to the Indo-West Pacific region, pp. 3-85. In: Muir JF, Roberts RJ (eds) Recent Advances in Aquaculture Volume 1. Croon Helm, London.

Macintosh DJ, Phillips MJ. 1992. Environmental issues in shrimp farming, pp. 118-145. In: de Saram H, Singh T (eds) Shrimp '92 Hong Kong. Infofish, Kuala Lumpur.

Mahmood N. 1987. Effect of shrimp farming and other impacts on mangroves of Bangladesh, pp. 46-66. In: Mepham RH (ed) Papers Contributed to the Workshop on Strategies for Management of Fisheries and Aquaculture in Mangrove Ecosystems, Bangkok, Thailand, 23-25 June 1986. FAO Fisheries Report 370 Supplement. Food and Agriculture Organization, Rome.

Makinen T, Lindgren S, Eskelinen P. 1988. Sieving as an effluent treatment for aquaculture. Aquacult. Eng. 7: 367-377.

Makinen T. 1991. Marine Aquaculture and Environment. Nordic Council of Ministers, Copenhagen, 126 pp.

Marsden W. 1994. Modern shrimp farming: sustainability and environmental impact. M.Sc. Thesis, University of Stirling, Scotland.

Martosubroto P, Naamin N. 1977. Relationship between tidal forests (mangroves) and commercial shrimp production in Indonesia. Mar. Res. Indonesia 18: 81-88.

Mekong Secretariat. 1992. Fisheries in the Lower Mekong Basin (Review of the Fishery Sector in the Lower Mekong Basin). Interim Committee for the Coordination of Investigations of the Lower Mekong Basin. Mekong Secretariat, Bangkok, 88 pp. + Annex.

Muir JF. 1982. Economic aspects of waste water treatment in fish culture, pp. 123-135. In: Alabaster JS (ed) Report of the EIFAC Workshop on Fish-Farming Effluent, Silkeborg, Denmark. EIFAC Technical Paper 41. Food and Agriculture Organization, Rome.

Nash G. 1990. *Penaeus monodon* grow-out diseases, pp. 172-190. In: New MB, de Saram H, Singh T (eds) Technical and Economic Aspects of Shrimp Farming. Infofish and the Fisheries Development Authority of Malaysia, Kuala Lumpur.

NCC. 1990. Fish Farming and the Scottish Freshwater Environment. Nature Conservancy Council, Edinburgh, 285 pp.

New M. 1990. Shrimp farming experiences environmental problems. EC Fisheries Cooperation Bulletin 3(3): 4-7.

NICA. 1992. Experiments on green mussel, *Mytilus* sp. and seaweed, *Gracilaria* sp. for biological wastewater discharged from intensive shrimp ponds. Technical Paper 6, 26 pp. National Institute of Coastal Aquaculture, Department of Fisheries, Songkhla, Thailand.

Odum HT, Arding JE. 1991. Energy Analysis of Shrimp Mariculture in Ecuador. Coastal Resources Center, University of Rhode Island, Narragansett, USA, 114 pp.

Office of Environmental Policy and Planning. 1994. The Environmental Management of Coastal Aquaculture. An Assessment of Shrimp Culture in Southern Thailand. Network of Aquaculture Centres in Asia-Pacific, Bangkok, 165 pp.

Phillips MJ, Lin CK, Beveridge MCM. 1993. Shrimp culture and the environment: lessons from the world's most rapidly expanding warmwater aquaculture sector, pp. 171-196. In: Pullin RSV, Rosenthal H, Maclean JL (eds) Environment and Aquaculture in Developing Countries. ICLARM Conference Proceedings 36, 359 pp. International Center for Living Aquatic Resource Management, Manila; Deutsche Gessellschaft fur Technische Zusammenarbeit (GTZ) GmbH, Eschborn.

Primavera JH. 1989. The social, ecological and economic implications of intensive prawn farming. SEAFDEC Asian Aquaculture 11(1): 1-6.

Primavera JH. 1991. Intensive prawn farming in the Philippines: ecological, social and economic implications. Ambio 20: 28-33.

Primavera JH. 1992. Prawn/shrimp culture industry in the Philippines, pp. 701-728. In: Fast and Lester (1992) above.

Primavera JH. 1993. A critical review of shrimp pond culture in the Philippines. Rev. Fish. Sci. 1: 151-201.

PSU. 1991. Pak Phanang Bay. Coastal Resources Institute, Prince of Songkhla University, Songhkla, Thailand.

Repetto R. 1994. Trade and Sustainable Development. United Nations Environment Programme, Geneva, 45 pp.

Robertson A, Phillips MJ. 1994. Mangroves as filters of shrimp pond effluent: predictions and biogeochemical research needs. Hydrobiologia (in press).

Rubel and Hager, Inc. 1979. Preliminary solids removal study. Rubel and Hager, Inc., Tuczon, Arizona.

Rubel and Hager, Inc. 1980. Wastewater treatment studies for commercial shrimp farm development at Puerto Penasco, Mexico. Rubel and Hager, Inc., Tuczon, Arizona.

Satapornvanit K. 1993. The environmental impact of shrimp farm effluent. M.Sc. Thesis, Asian Institute of Technology, Bangkok.

Schnick RA. 1991. Chemicals for worldwide aquaculture, pp. 441-467. In: ADB-NACA (1991) above.

Silas EG. 1987. Significance of the mangrove ecosystem in the recruitment of fry and larvae of finfishes and crustaceans along the east coast of India, particularly the Sunderbans, pp. 19-34. In: Report of the Workshop on the Conversion of Mangrove Areas to Aquaculture, Iloilo City, Philippines, 24-26 Apr 1986. UNDP/UNESCO, New Delhi.

Sirisup S. 1988. Socio-economic changes in the course of commercialization: coastal aquaculture in Chanthaburi Province, Thailand. M.Sc. Thesis, Asian Institute of Technology, Bangkok.

Snedaker SC, Getter CD. 1985. Coastal Resources Management Guidelines. Coastal Management Publication No. 2. Renewable Resources Information Service, Research Planning Institute, Inc. US Agency for International Development and National Park Service, Washington DC.

Tanvilai D, Songsangjinda P, Chiayakum K. 1993. Variation of Sediment Quality and Quantity in Intensive Tiger Shrimp Culture Ponds. Technical Paper 5, 200 pp. National Institute for Coastal Aquaculture, Department of Fisheries, Songkhla, Thailand.

Turner RE. 1977. Intertidal vegetation and commercial yields of penaeid shrimp. Trans. Amer. Fish. Soc. 106: 411-416.

Wang JK. 1990. Managing shrimp pond water to reduce discharge problems. Aquacult. Eng. 9: 61-73.

Wang JK, Fast AW. 1992. Shrimp pond engineering considerations, pp. 415-429. In: Fast and Lester (1992) above.

Warrer-Hansen I. 1982. Evaluation of matter discharged from trout farming in Denmark, pp. 57-63. In: Alabaster JS (ed) Report of the EIFAC Workshop on Fish-Farming Effluent, Silkeborg, Denmark. EIFAC Technical Paper 41. Food and Agriculture Organization, Rome.

Welcomme RL. 1988. International Introductions of Inland Aquatic Species. FAO Fisheries Technical Paper 294, 318 pp. Food and Agriculture Organization, Rome.

Wickins JF. 1985. Ammonia production and oxidation during the culture of marine prawns and lobsters in laboratory recirculation systems. Aquacult. Eng. 4: 155-174.

Wiley KC. 1992. The application of environmental assessment to the management of risk in shrimp aquaculture in Southeast Asia, pp. 146-152. In: de Saram H, Singh T (eds) Shrimp '92 Hong Kong. Infofish, Kuala Lumpur.

Williamson MR. 1989. Development of a silt pump for aquacultural ponds. Aquacult. Eng. 8: 95-108.